Implementation of Fully Differential OTA based on Commercially Available IC for Biquadratic Filter Application

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***Abstract*—This article presents a realization of a recently basic building block for analog signal processing, namely fully differential operation transconductance amplifier (FD-OTA) using the commercially available ICs (LT1228). The proposed element has very simple internal instruction. The performances are examined through PSpice simulations. The description include example as biquadratic filter topology. They show good agreement as theoretically depicted.**

***Index Terms*—FD-OTA, commercially available IC, biquadratic filter, building block application**

I. Introduction

The operational transconductance amplifier (OTA) is a basic building block in analog circuit applications [1], such as wireless communication, computer systems, biomedical circuits, and instrumentation and control systems [2-3]. The OTA received considerable attention as active components, because the transconductance can be adjusted electronically. The key function of the OTA is to convert the input voltage into the output current while accuracy and linearity are both maintained [4]. The flexibility of the device to operate in both current and voltage-modes allows for a variety of circuit designs. The fully differential (FD) structures are often used in industrial products because of the improved dynamic range over their single-ended counterpart [5]. This is due to the properties of the FD structures have better common-mode noise rejection, reduce harmonic distortion, and increased output current swing [6]. Recently, FD-OTA has been often used in many filter applications such as OTA-C filter in [7-14]. The OTA-C filters are an attractive choice for applications where a tunable filter is required. Even when the tunability in frequency is not a requisite, these filters can easily be used with an automatic frequency tuning system [15]. Structures are well known for realizations of simple filters as biquads, that can be cascaded for more complex filters, for simulations of passive doubly-terminated LC filters [16], preferred for their low sensitivity to element variations, and for other kinds of filters. However, FD-OTA is an important element building block for filters, but it is not implementation in commercially available IC. This paper proposes the implementation of FD-OTA that is implementation by using commercially available ICs (LT1228). The proposed element has very simple internal instruction. The performances of the proposed FD-OTA are proved by PSpice simulations. The application example as a biquadratic low pass filter is included. They show good agreement as theoretically depicted.

II. FD-OTA Configulation

An ideal FD-OTA has infinite input and output impedances. The output current of a device is given by

$$I_o^+ = g_m(V_i^+ - V_i^-) \tag{1}$$

and

$$I_o^- = g_m(V_i^- - V_i^+) \tag{2}$$

where g_m is transconductances gain of the FD-OTA. For LT1228 commercially available IC of the OTA can be express by

$$g_m = \frac{I_B}{3.87V_T}. \tag{3}$$

Where V_T is the thermal voltage (about 25mV at room temperature). The symbol and equivalent circuit of the FD-OTA are illustrated in Fig. 1(a) and (b), respectively. The proposed implementation of FD-OTA based on LT1228 commercially available IC is shown in Fig.2. The output current of the FD-OTA for non-ideal case is given by

$$I_o^+ = \alpha_o^+ g_m(V_i^+ - V_i^-) + \varepsilon_o^+ \tag{4}$$

and

$$I_o^- = \alpha_o^- g_m(V_i^- - V_i^+) + \varepsilon_o^- \tag{5}$$

where α_o and ε_o are current gain error and current offset error, respectively.

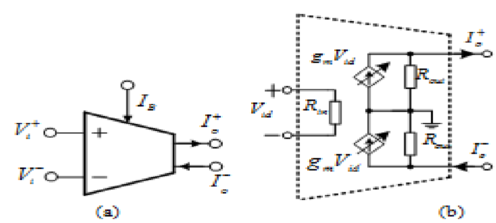

Figure 1. The FD-OTA (a) Symbol (b) Equivalent circuit

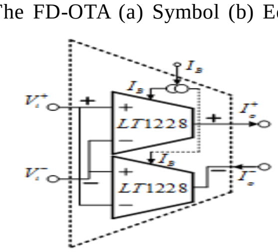

Figure 2. Implementation of the FD-OTA based on commercially available ICs

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III. Simulation Results

To prove the performances of the proposed FD-OTA, the PSpice simulation program was used for the examination. We use the conventional OTA LT1228 models from the PSpice library. The supply voltage $V_{CC} = -V_{EE}$ were set to 15V. A wide range of the transconductance controllability can be achieved as shown in Fig. 3, when I_B is varied from $1\mu A - 1mA$. DC transfer characteristics between voltage differential input V_{id} and current output I_o are shown in Fig. 4. DC characteristics between voltage differential input V_{id} and transconductance g_m, when I_B is varied, 10µA/step of 10 steps, from 10µA to 1mA, are shown in Fig. 5. The bandwidths of the output terminals relative to v_i^+ and v_i^- are shown in Fig. 6 and Fig.7, respectively. The $-3dB$ responses of I_o^+/V_i^+, I_o^-/V_i^+, I_o^+/V_i^- and I_o^-/V_i^- is located at 13.283MHz. The power consumption relative to I_B is shown in Fig. 8, when I_B is varied from 10µA to 1mA. Conclusions of FD-OTA parameters are displays in Table I.

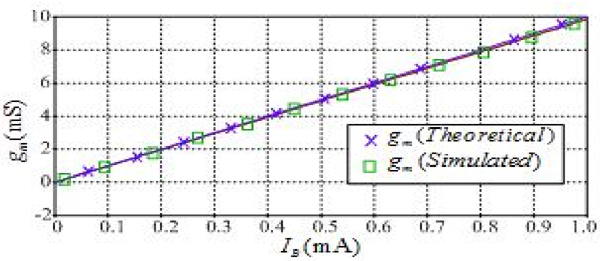

Figure 3. Transconductance relative to I_B.

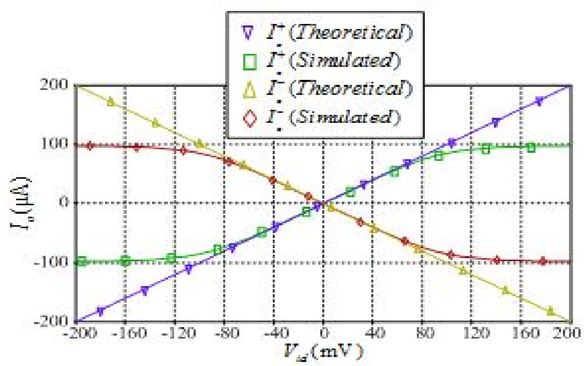

Figure 4. DC transfer characteristics

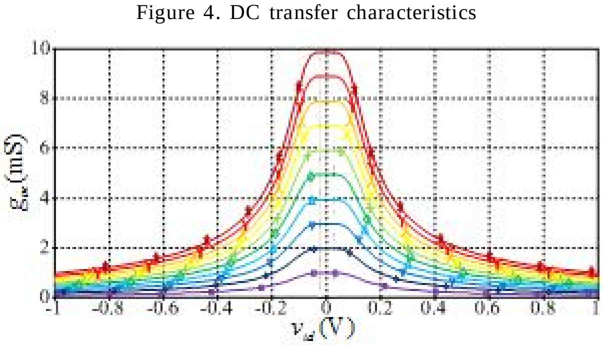

Figure 5. Transconductance relative to v_{id} and I_B

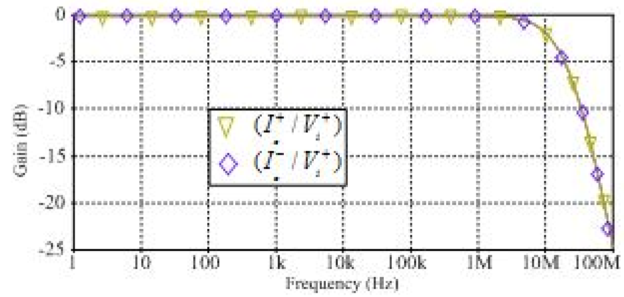

Figure 6. Frequency response of output terminal relative to v_i^+

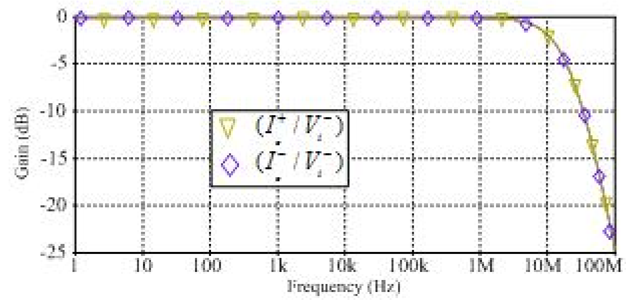

Figure 7. Frequency response of output terminal relative to v_i^-

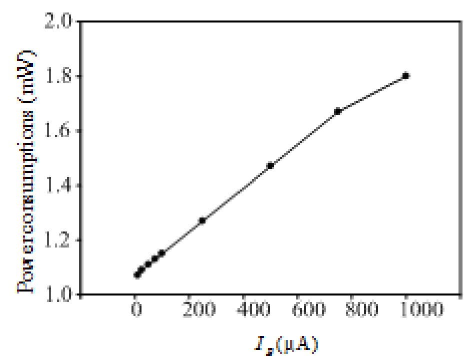

Figure 8. Power consumptions relative to I_B

TABLE I. Conclusions Of FD-OTA Parameters

Parameters	This work
Power supply voltages	±15V
Power consumption $10\mu A \le I_B \le 1mA$	1mW-2mW
Switching time delay	463ns
-3dB Bandwidth	13.283MHz(I_o^+/V_i^+), 13.283MHz (I_o^-/V_i^+), 13.283MHz (I_o^+/V_i^-), 13.283MHz (I_o^-/V_i^-)
Input bias range for controlling transconductance valuer	1µA-1mA
Transconductance	<10mS
CMRR(dB)	313.236

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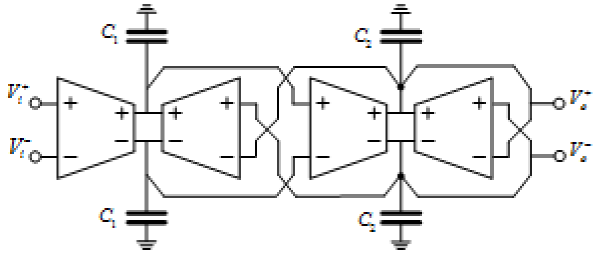
Figure 9. Conventional biquadratic OTA-C filter topology

IV. Application Example and Simulation Results

The application of the proposed FD-OTA based on commercially available IC is biquadratic filter shown in Fig. 9. It consists of 4 FD-OTAs. Considering the circuit in Fig. 9, and using the FD-OTA properties, yields the transfer function voltages as follows

$$H(s)=\frac{v_o^+-v_o^-}{v_i^+-v_i^-}=\frac{\frac{4g_m^2}{C_1C_2}}{s^2+\frac{2g_m}{C_2}s+\frac{4g_m^2}{C_1C_2}}. \tag{6}$$

The transfer function of the general low pass biquadratic filter can be express by

$$H(s)=\frac{\omega_p^2}{s^2+\frac{Q}{\omega_p}s+\omega_p^2}. \tag{7}$$

Comparing (6) and (7), the following expression can be derived

$$\omega_p=2g_m\sqrt{\frac{1}{C_1C_2}} \tag{8}$$

and

$$Q=\frac{4g_m^2}{C_2}\sqrt{\frac{1}{C_1C_2}}. \tag{9}$$

Considering the circuit in non-ideal case, yields the transfer function voltages as follows

$$H(s)=\frac{\frac{4\alpha_o^2g_m^2}{C_1C_2}}{s^2+\frac{2\alpha_o g_m}{C_2}s+\frac{4\alpha_o^2g_m^2}{C_1C_2}}. \tag{10}$$

It is clearly seen from (10), FD property is that the offset error can be cancelation. Comparing (7) and (10), the following expression can be derived

$$\omega_p=2\alpha_o g_m\sqrt{\frac{1}{C_1C_2}} \tag{11}$$

and

$$Q=\frac{4\alpha_o^2g_m^2}{C_2}\sqrt{\frac{1}{C_1C_2}}. \tag{12}$$

From (11) can be re-expressed as

$$\alpha_o=\frac{\omega_p}{2g_m\sqrt{\frac{1}{C_1C_2}}} \tag{13}$$

The biquadratic filter topology in Fig. 9 was designed to have low pass filter response for $C_1=C_2=14.14$nF. The designed filter was simulated with PSpice program. Fig.10 shows simulated the AC frequency response of the designed filter with differential bias current. Differential mode and common mode gain are shown in Fig.11. The frequency response of the total noise for the filter topology is shown in Fig.12. Output and input transient waveforms are shown in Fig.13.

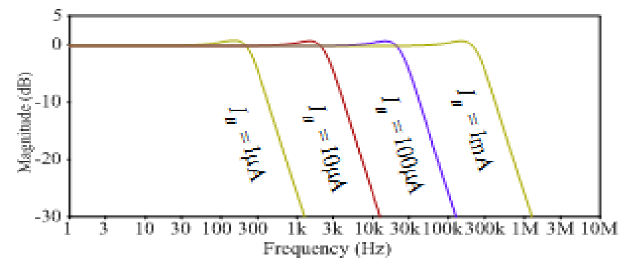

Figure 10. Frequency response biquadratic filter at different bias current

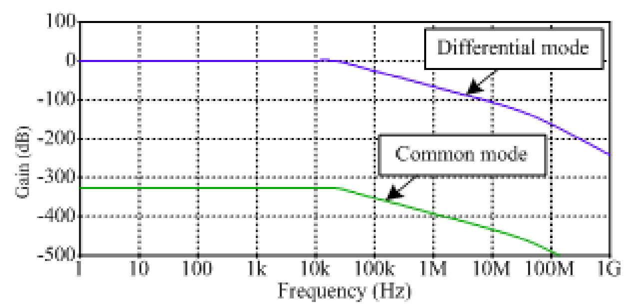

Figure 11. Frequency response of differential and common mode

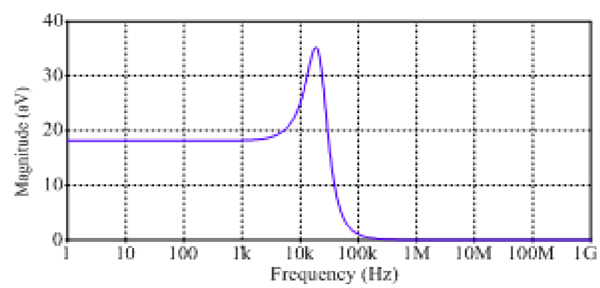

Figure 12. Frequency response of the total output noise for the biquadratic filter

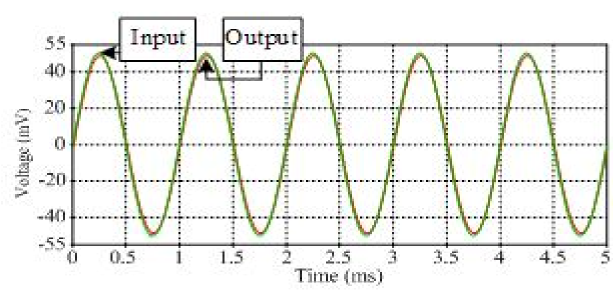

Figure 13. Transient waveforms of biquadratic filter

Conclusions

The building block, called the FD-OTA implemented by using commercially available ICs, has been introduced via this paper. The internal construction is very simple. The usabilities have been verified by the simulation and application example. The application circuit is biquadratic low pass filter. They show good agreement as theoretically depicted. Our future work is to find more applications of the FD-OTA, emphasizing on the current-mode and voltage-mode applications such as signal generator, rectifier, filter and etc.

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